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EFFECT OF GAS DISTRIBUTOR ON THE HYDRODYNAMICS OF FLOTATION COLUMN

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ABSTRACT: Proper understanding of gas/liquid contacting in flotation columns is limited by the fact that most published information deal with the highly-coalescent pure gas/liquid systems whereas virtually all industrially-relevant systems contain solutes which hinder bubble coalescence Consequently, the influence of the entrance conditions generated by the gas distributor at the bottom of the reactor may extend to elevations much higher than those observed in experiments conducted using highly-coalescent systems This, in turn, can strongly influence the hydrodynamic conditions, concentration profiles, and mass transfer characteristics achievable in multi-phase reactors. In this investigation the effect of sparger design on the hydrodynamics of flotation column was investigated under conditions where coalescence rate was controlled through the introduction of frothers. Depending on the sparger performance and coalescence rate, up to 15 fold increase in interfacial area of contact was obtained and gas holdups as high as 0 43 were also observed

1 INTRODUCTION

The effect of sparger design and interfacial characteristics on the hydrodynamics of bubble/flotation column is of concern to many fields such as mineral processing, chemical engineering, and agriculture engineering (Mikkilinem and Knickle 1985, Xu and Finch 1989; Weber et al, 1990, Tsuchıya and Nakanishi 1992; Nagahiro et al, 1992; Cramers et al, J992, Glasgow and Rainbolt 1994, Al Taweel et al, 1995) In flotation columns, good contact between gas and liquid is required Hence, the gas is usually introduced through a distributor where it is dispersed to form bubbles In these devices high interfacial areas can be obtained by generating small bubbles which have a large surface to volume ratio *and rise* more slowly through the liquid, thus providing longer contact time Furthermore, distributors provide a simple mean for agitating the liquid Analytical and empirical relations involving the bubble size and operating variables for efficient flotation have been reported by many investigators Generally, the flotation rate constant is inversely *proportional to* the bubble size *as* reported by Ahmed and Jameson (1985), Szatkowski and Frcyberger (1985) and Szatkowski (1987) So, high flotation rate can be achieved by using small bubbles through the flotation process A variety of sparger designs (gas distributors) have been proposed for generating small bubble size to increase the flotation performance The spargers used should be able to provide bubbles of the desired size (and size distribution) and be capable of varying these to meet changing processing requirements. They should also be robust, easily maintained, exhibit little tendency to be plugged The velocity of flow at the tip of the sparger should also be low in order to minimize axial mixing and operational instabilities in columns The selection and design *of* the spargers are particularly important aspects in all flotation columns Unfortunately, limited information are available concerning the effect of spargers on the hydrodynamics of flotation column and most of the investigations were conducted using pure liquids although tremendous increase in interfacial area was obtained *in* the presence of coalescence - hindering materials as indicated by Al-'I awee! et al (İ995)

2 NOMENCLATURE

a	interfacial area of contact	m /ni
Ah	the difference m water level in manometers	nun
L	distance between the Plexiglas tubes	mm
A/-	the distance between piezometer laps	(I 17 m)
$U_{(1}$	Superficial jiJis velocity	em/s
N|.	ιιιnιbn ol bubble^	

U_l	Superficial feed liquid velocity	cm/s
Q_G/Q_L	Gas/liquid ratio which runs to the sparger	
d_T	throat diameter of two-phase venturi spargers	mm
ΔP	Pressure drop through the sparger	N/m"
J_{GL}	drift flux between gas and liquid	cm/s
ϵ_G	fractional gas holdup	

Subscripts

G	gas
L	liquid
Cnt	Critical
b	bubbles
T	throat

3 EXPERIMENTAL SETUP

The experimental setup involved in this investigation is schematically depicted in Figure 1 It consists of a vertical glass cylindrical column of 0 I m diameter and 2 67 m height Bubbles are generated at the bottom of the column using two-phase venturi spargers which control the size and the size distribution of the bubbles generated Four spargers having different throat diameters were used m this investigation Frother solutions (Dowfroth 250 C) at the desired concentration were charged to the feed line at the top of the column and to the motive water which enters to the sparger at the bottom of the column by means of piston dosing pumps Measurements were undertaken only after equilibrium conditions (as evidenced by constant optical density measurements) were achieved

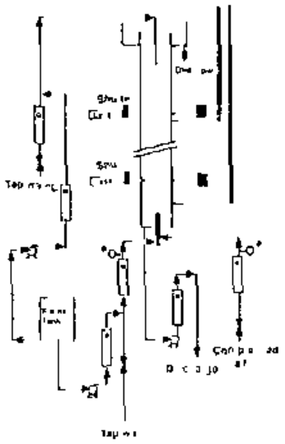
4 MEASUREMFNT TECHNIQUES

Gas holdup was measured by using two pie/ometnc lubes connected to the wall-mounted pressure taps arranged at 26 cm and 143 cm above the tip of the ipaiger Special precautions were taken to eliminate the intelligence oi the dynamic head in gas holdup measuiemtrnts Accurate static pressure measurement (al + Q 5%) were thus obtained The following equation was applied lo calculate the gas holdup

$$\epsilon_G = \frac{\Delta h}{\Delta Z} \qquad (1)$$

where *F,,* - gas holdup. Ah the difference in walu level m manomılus and A/ ~ flu distance IICIWLL.II piezometer taps (I 17 m) At the same two positions the interfacial area of contact in the column was measured using a laser-based light attenuation technique (Kasireddy and Al Taweel, 1990) This technique provides a measure of the average interfacial area along the path of the light beam It can thus be used for measuring average values throughout the column as well as local values

In order to measure the interfacial area in the column, two specially designed plexiglas tubes are inserted from the side walls and their location was adjusted to provide the desired measuring path between their tips, L The first step in recording data is to determine the original light intensities This is done by integrating the picoammeter output for a certain amount of time, usually 128 seconds Once these data are recorded, flowmeters, and hence air flows, are set at desired levels As fluctuations in the rotameter readings dampen, the true values are noted and the flow rates in liters per minute are determined from corresponding flow charts When the flow has been stabilized, the new light attenuation readings begin their integration sequence This is usually done over a longer span of time, normally 256 seconds As the light intensities are being determined, the piezometer levels are recorded to indicate the value of gas holdup



'•fi I Schematic dıagıam of the expetimental setup

Gas flow hitc liquid llow rate pressuıc dıop and liolhu uHKumalinn aie controlled by flowmeter and ŋi Lssui i singes fixed on the control panel

5 SYSTEMS INVESTIGATED

A continuous system consisting of tap water/air/surfactant was used in this investigation Tap water supplier and compressed air supplier were used after filtration process to make sure that they are free from any contaminants Polypropylene Glycol Methyl Ether, with commercial name of Dowfroth 2-50 C [CH,-(OC\H$_{6}$)$_{3}$OH], at different concentrations (0-20 ppm), was used as frother It was supplied by Dow Chemical Canada Inc with the following properties density = 0 9895 kg/I, viscosity = 16 68x 10 ' Pa s, surface tension = 0 0263 N/m, and molecular weight = 206 28 g/mole

Testing procedures are also executed on a system of water and air only, in the absence of the surfactant This condition satisfies a rapidly coalescent system against the highly coalescent system described above

6 PARAMETERS CONSIDERED

The effects of sparger throat diameter and superficial gas velocity on the hydrodynamics of flotation column were investigated The ranges of the investigated parameters are shown in Table I

Table I Investigated Experimental Conditions

Superficial gas velocity, U_c,	0-3	cm/s
Superficial liquid motive velocity lo the sparger	0-0 4 S	cm/s
Superficial feed liquid velocity, U_L	0-3	cm/s
Gas/lrquid ratio, *Qt,/Qt,* which runs to the sparger	0 I - 36	———
Throat diameters of the two-phase ventun spargers		
di - 0 86 mm	d_t - 1 17 mm	
d| = 1 60 mm	dj = 2 17 mm	
H other concentration	0-10	ppm
Pressure drop	2 1x10^{s}	N/nT

/ RESULT S AND DISC \ ISSIONS

CMS holdup and flow regimes

Gas holdup is an nnpoitant design and operating [Miami in thai is commonly used lo desmhe the bvilioiiviirimiLs in ilolalion loliiinns I his tan be LİL'arK indicated bv the relationship between gas holdup and superficial gas velocity in flotation column

In the case of rapidly coalescent system (Figure 2) the effect of superficial gas velocity on gas holdup was found to follow closely the pattern generally reported in the literature by ltyokumbul, (1994) and Deckwer, (1992) Gas holdups as high as 0 15 were obtained and smooth transition between the various flow regimes was observed

However, in the case of slowly-coalescent systems (Figure 3) a different flow pattern was found to occur where peaked value is recorded in a transition zone One can interpret this phenomenon by arguing that gradual increase of the superficial gas velocity, U<,, causes the population density of bubbles, N_h, to increase until it reaches the maximum limit beyond which any increase in U<, makes the coalescence process to promote (Figure 4) This may be due to the increase of collision probability between bubbles as a result of increasing their population density The condition before which the maximum limit of population density appears can be called as bubhiv flow regime This limit is defined by reaching the so called critical superficial gas velocity, $U_{(ri\ n}$, in Fig 3 So, under this condition the gas holdup increases almost linearly until it reaches the maximum limit

The condition of bubbly flow regime can be distinguished by the existence of small bubbles having 200 - 500 u,m size range These tiny bubbles could be the result of the fully dispersed flow encountered in the throat of the sparger and due to the limited chance of coalescence process at the point dl measurement These conditions may lead to the prevention of the collision process between bubbles as well as the continuous increasing nl gas holdup lo the maximum limit

After the cnlical point of superficial gas velocity ı e beyond the maximum limit of bubbles population dcnsitv, the crowdness of bubbles make a piob.ihilit\ of collision between (hem to occui As a usul? of that Ihe coalescence rate can be piomolcd 1 indi r the same conditions a hactron of the gas Ihiouglipui also tianspoils lo the top of the column in the hum ol large and fast bubbles so that two different c)ass$_{L}$s ol bubbles begin lo appeal in this region So ",i holdup was found to decrease shaiply in this uuinn and in subsequent e the population densily ol bubble I lie conditions undei winch this phenomenon take, plate tan be tailed the tiansition flow regime I lu regime tould lie considered as the Jusi siaüc ol tin hilly developed tlıuıı turbulent fkm KLUIIIL

By increasing the superficial gas velocity higher than the value encountered in transition flow, the population density of bubbles was found to decrease and the flow becomes a recirculating one. Under these conditions, the bubbles coalescence and breakage repeatedly take place as they rise up through the column until they reach the equilibrium state The prevailing regime in this zone is the fully churn-turbulent one.

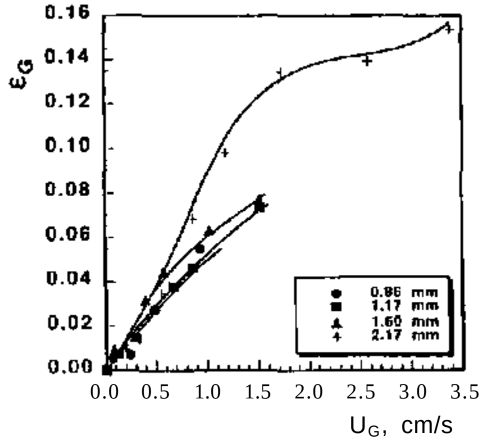


Fig 2; Effect of superficial gas velocity on gas holdup in rapidly-coalescent system at vanous throat diameters
(Ap = 2 1x10^s N/m^3, frother conc.=0ppm, U!= 0 cm/s)

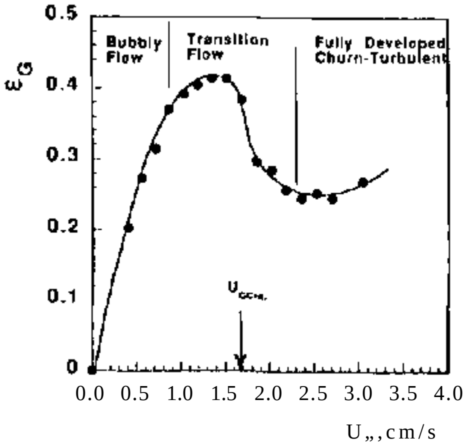


Fig 3'Effect of superficial gas velocity on gas holdup in slowly-coalescent system,
(d! -'- 2.I7 mm, Ap •-• *2* lxlo\ frother enne I0 ppm, Ui. = 3 cm/s)

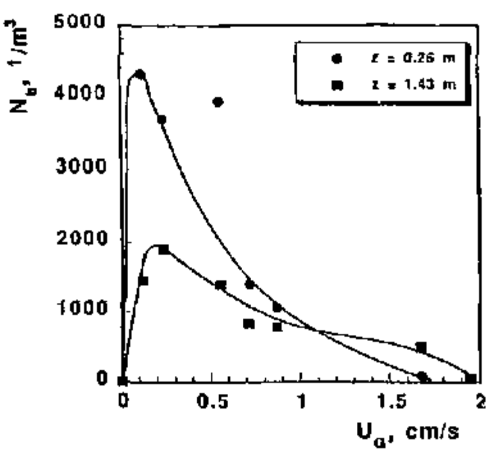


Fig 4 Effect of superficial gas velocity on bubble population density in slowly-coalescent system at different levels.
(d_T = 1.6 mm, Ap = 21x10' N/m^2,
frother cone. = 10 ppm, UL = 0 cm/s)

Interfacial area

The interfacial area was found to play a vital role m determining the hydrodynamics of flotation column. Higher interfacial area was obtained by using spargers with large throat diameter that can disperse the gas stream into small bubbles which have a large surface to volume ratio and which rise more slowly and thus stay longer in the pulp zone It is interesting to notify here that, in systems containing surfactant, two regions with a peak in-between are existing on the plot of the interfacial area against the superficial gas velocity (Figure 5)

In the highly-coalescent system the interfacial area was found to depend on the size of the generated bubble at the entrance zone (Figure 6) It is obvious from this figure that the interfacial area obtained for the large diameter sparger (2 17 mm throat diameter) is higher than (hose *of* small *ones This* can be attributed to the sufficient residence time available for bubbles in larger throat sparger This prolonged residence time causes the fully developed dispersion regime to prevail and in consequence smaller bubbles with higher interfacial area can exist

On the other hand, the slowly-coalescent system was (bund to behave completely differeni than Ihat of highly-coalcscent system As shown in Figure 7, in the bubbly flow regime, the iniei facial area was found to increase rapidly with increasing the superficial gas velocity until it reaches a maximum at the critical superficial gas velocity, Uccni In the transition region, the interfacial area was found to decrease by increasing the gas velocity. However, the decreasing rate is very small in the initial stages but accelerates rapidly as the transition to churn-turbulent flow is approached. This is most probably caused by the dominance of small bubbles in the initial stages of the transition region. As regards the succeeding sharp decrease of the interfacial area, this is most probably caused by the excessive formation of large bubbles having small specific interfacial area and high rise velocities so that reduction in gas holdup takes place.

In spite of the fact that gas holdup seems to have, more or less, constant value against the change of gas velocity in the chum-turbulent flow regime (Fig.3), the interfacial area was proved to suffer drastic decrease under the same conditions (Fig. 7), This is most probably due to the high intensity of agitation which prevails in this regime and stimulates the tendency towards the formation of bubbles of intermediate size through the breakage of large bubbles on one hand and the coalescence of small bubbles on the other hand.

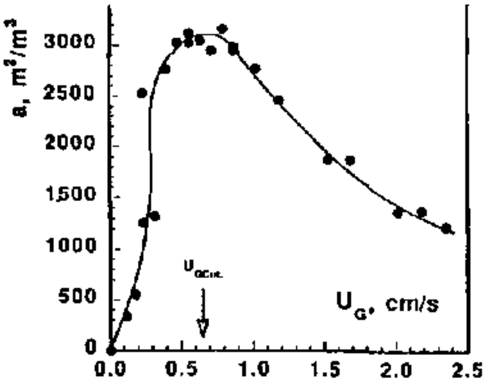


Fig. 5' Effect of superficial gas velocity on interfacia! area of contact in slowly-coalescent system (d_T = 16 mm, Δp = 2x10^s N/m^2, frother cone = 10 ppm, U_L = 3 cm/s)

It is also worthy here to notice that a slowly-coalescent system (Fig. 7) generates interfacial area which is extremely larger than that relevant to a highly coalescent one (Fig. 6) at the same operating conditions. This is, of course, due to the effect of the frother which suppress the coalescence action and hence larger interfacial area is acquired

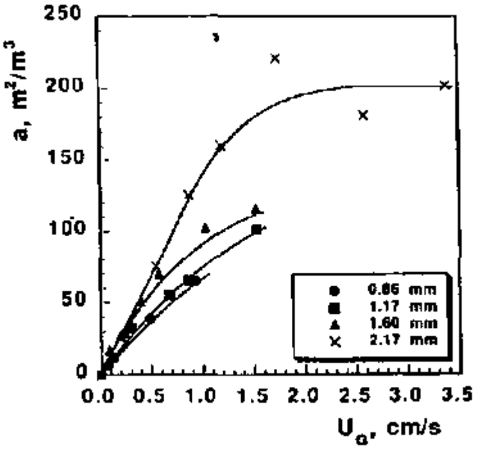


Fig. 6: Effect of superficial gas velocity on interfacial area in rapidly-coalescent system at various throat diameters (Ap = 2x10^s N/m^z, frother cone- = 0 ppm, Ui, = 0 cm/s)

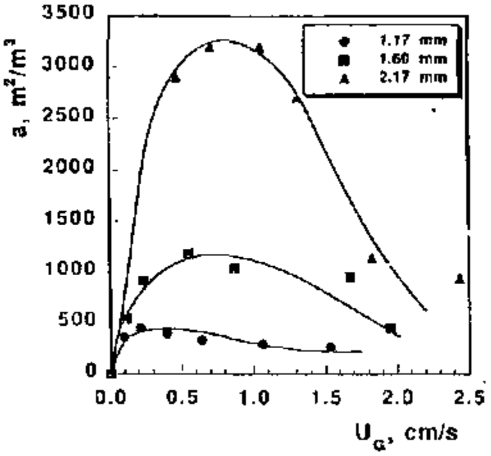


Fig. 7. Effect of superficial gas velocity on interfacial area in slowly-coalescent system at various throat diameters

(Ap = 2xlO^i N/m^2, frother cone It) ppm, LI, 0 cm/s)

Drift flux

Drift flux approach is very useful in characterizing the types of flow in column flotation The drill flux is defined as the volumetric flux of gas relative to the

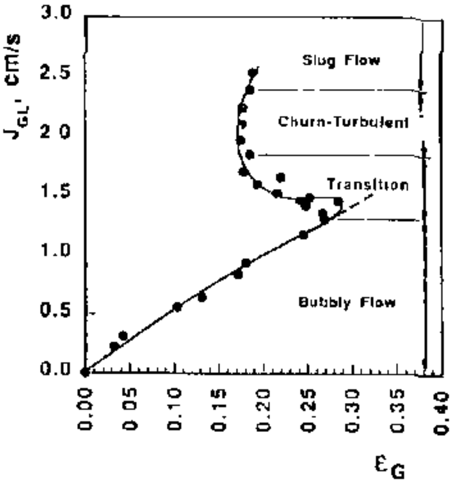
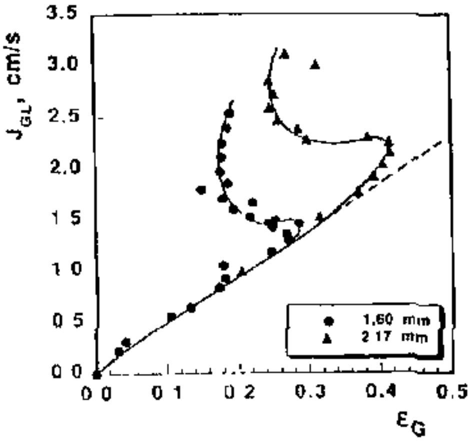


Fig 8 Effect of gas holdup on drift flux
(di = 1 6 mm, frolher cone = 10 ppm, Ap - *2* IxlO^1 N/m^2, U$_t$ = 3 cm/s)



Tig 9 Eflect of throat diameter on drift flux
(fmtliei cone - 10 ppm, Δp = 2 1x10^7, U$_l$ = 3 cm/s)

snildce moving at an average velocity It can be txpi essed as,

$$j_{GL} \quad (1 - \varepsilon_G) U_G \pm \varepsilon_G U_L \qquad (2)$$

where jcu = drift flux, e$_{(}$, = gas holdup, U« = superficial gas velocity, and U| = superficial liquid velocity

Drift flux versus gas holdup plot, is the most beneficial tool in predicting flow regimes tn flotation columns As can be seen from Figure 8, the drift flux diagram clearly shows the transition from the bubbly flow regime to the churn-turbulent flow regime From this figure the drift flux was found to increase linearly by increasing the gas holdup in the bubbly flow regime In conti ast, the transition flow regime reflects slight increase of the drift flux if the gas holdup is decreased Moreover, the drift flux is subjected to a more or less upward increase at almost a constant value of gas holdup m the case of the churn-turbulent regime

Fig 9 expresses the effect of sparger throat diameter on the relationship between the drift flux and the gas holdup It is very evident from this plot that the transition flow regime is expected to take place later on with the spargers of biggei throat diameter This conclusion signifies that transition from bubbly flow regime to churn-turbulent regime in such a case is associated with higher value of gas holdup which is the direct result of the tendency of the spargeis of large throat diameter to produce excessive amounts of smaller bubbles if they are compared with the spargers having smaller throat diameters

8 CONCLUSIONS

In the case of lapidly-coalescent systems, gas holdups of up to 0 15 were obtained and smooth transition between the vanous flow regimes was observed On the othei hand, m the stowly-coalescenl systems different flow pattern was found to occur A critical superficial gas velocity, U,,,$_{n}$,, at which the gas holdup-superficial gas velocity curve (e$_{(1}$- U$_{(>}$) deviates from the linearity was observed By increasing the superficial gas velocity beyond the critical value, the gas holdup was found to decrease sharply until it leaches a minimum value With further increasing of the superficial gas velocity beyond the limits of lı diısıtıon flow ı egime, gas holdup was observed to acqmie, a more ot less, conslanl value thiough the churn-Ujrbulcnl flow regime

Higher gas holdups, up to 0 41, were obtained by using spargeis with large throat diameters thai can disperse the gas stieam into small bubbles which have a large smface to volume idim and which use more slowly and thus stay lonyet in the pulp Amc

Interfacial area was found to play an important role in determining the hydrodynamic conditions in flotation columns. Higher interfacia! areas had been recorded for a slowly-coalescent system than those relevant to the rapidly-coalescent one. Moreover, the latter system showed smooth transformation between the different flow regimes. In the systems containing surfactant, ı e, slowly-coalescent, two trends with a peaked interfacial area in-between were observed on the plot of the interfacial area against the superficial gas velocity. The mutual interaction between the superficial gas velocity and the coalescence action was applied in order to interpret the mode of change of the interfacial area in the investigated systems. It was also proved that the spargers with bigger throat diameters are able to generate larger interfacial areas as they usually produce bubbles of smaller sizes which have higher surface to volume ratio

Drift flux versus gas holdup relationship was found to be useful in predicting the flow regime in flotation columns. It was applied to define the transition point (or zone) at which the flow regime departs from the bubbly regime to the churn-turbulent one. This transition zone was found to be influenced by the size of the sparger throat which controls the size of the generated bubbles

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